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The effect of tine, wing, operating depth and speed on the draft requirement of subsoil tillage tines

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Abstract

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In this study, the effect of tine type, adding wing, operating depth and forward speed on the draft requirement of subsoil tillage tines was investigated in clay loam soil. Three subsoil tillage tines (subsoiler, bentleg and paraplow), four levels of forward speed (1.8, 2.3, 2.9 and 3.5 km/h), three levels of depth (30, 40 and 50 cm) and winged and no-wing tines were examined with the exception of bentleg as it would not be winged. It was revealed that draft of the tines is less affected by forward speed but is much affected by tine type, depth and wing. It was observed that an increase of speed and depth plus adding wing results in an increase of draft in all tines. Additionally, it was found that in all depths and speeds, subsoiler required more draft than paraplow and paraplow required more draft than bentleg. Multiple regression models including the studied parameters were developed to predict the draft requirements for each tine with high accuracy.

Keywords: soil; subsoiler; bentleg; paraplow; compaction

The prediction and availability of draft requirement data for tillage implements is an important factor in selecting suitable tractor and tillage implement for a particular farming situation (Alimardani et al. 2008). Therefore, the measurement of implement draft and developing draft prediction equations has received most of the attention in field tests (Kheiralla et al. 2004; Manuwa, Ademosun 2007; Manuwa 2009; Abo Al-Kheer et al. 2011; Askari et al. 2011; Moeenifar et al. 2014; Ramadhan 2014; Ranjbarian et al. 2015). The draft requirement of any tillage implement was found to be a function of soil properties, tool geometry, working depth, travel speed, and width of the implement (Glancey et al. 1996).

Subsoiling in compacted soils requires high draft and is an expensive operation. Therefore, conventional subsoiler associated with high-energy demand and the possibility of soil re-compaction, was replaced by other tools such as bentleg and paraplow (Durairaj, Balasubramanian 1997; Esehaghbeygi et al. 2002; Celik, Raper 2012). Wings were attached to the sides of the subsoiler and paraplow with a view to improve their performance in increment of soil loosened area and decrement of specific resistance (Spoor, Godwin 1978; Ramadhan 2011, 2014). Many authors reported the effect of adding wings on draft increment (Spoor, Godwin 1978; Godwin et al. 1981; Ahmed, Godwin 1983; Desbiolles et al. 1997; Di Prinzio et al. 1997; Arvidsson et al. 2004; Ramadhan 2011, 2014). Many researches were conducted about the effect of depth and forward speed on force requirements of subsoil implements (Spoor, Godwin 1978; Glancey et al. 1996; Desbiolles et al. 1997; Al-Suhaibani et al. 2006; Ramadhan 2011, 2014).

Mathematical models have been developed to predict draft of tillage tools, but the soil complex

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Table 1. Summary of the experiment conducted

Tine	Independent parameters			Dependent parameters
	depth (cm)	forward speed (km/h)	wing	
Subsoiler	30	1.8	30 cm wing	
Paraplow	40	2.3	no-wing	draft
Bentleg	50	2.9		requirement

manner caused the complicated interactions between a tillage tool and the soil. Summers et al. (1986), Bashford et al. (1991) and many authors developed draft mathematical equations for tillage implements and found that variations in climatic conditions, soil moisture, soil hardness and soil type made it difficult to obtain repeatable draft data. Furthermore, Buston and Rackham (1981) found no mathematical models to predict draft of tillage tools accurately. ASABE standard D497.6 (ASABE 2009) provides one of the main mathematical expressions of draft for tillage tools in different soil conditions. This standard does not supply draft of some tools like paraplow and bentleg.

Moreover, many regression equations for the draught prediction of various tillage implements have been developed using the data collected from the field experiments and different prediction software to facilitate machinery selection and implement matching with tractor (ASAE 2000; Kheiralla et al. 2004). In these studies, the tillage tools were tested to measure draught at the desired operating depth, speed and so on.

In comparison, it is obvious that less attention has been simultaneously given to effects of tine, adding wing, operating depth and forward speed on draft requirement of subsoil tillage tines especially in field conditions since it prepares real conditions to be evaluated precisely. Furthermore, Iranian farmers do not use bentleg and paraplow plus wings as a supplement for subsoiling operation and few researches on the effects of adding wings to the subsoil tines on draft and other soil properties were conducted in Iran and it was needed to conduct a research about them in local conditions of Iran

With regard to the mentioned matters, the following objectives were considered for the present study:

(1) Investigating the simultaneous effect of speed, depth, tine and wing on draft requirement of subsoil tillage tines.

(2) Development of regression models for prediction of the draft of subsoiler, paraplow and bentleg as main subsoil tillage tines.

(3) Presentation of the obtained results for encouraging Iranian farmers to use the subsoiler, paraplow, bentleg and wing as supplement.

MATERIAL AND METHODS

Field measurement. The field tests were conducted at the Ardabil Agricultural Research Centre (48°55'47'E, longitude; 37°33'57'N, latitude; and 1,350 m a.s.l.). The site had a 0 to 1% slope and had barley stubble residues from the previous farming season. This experiment was conducted with the three depths of 30, 40 and 50 cm, four speeds of 1.8, 2.3, 2.9 and 3.5 km/h at three tines of subsoiler, paraplow and bentleg and two levels of wing including winged and not-winged tines with the exception of bentleg as it was not winged. The summary of treatments being tested is shown in Table 1 and the tools used are depicted in Fig. 1.

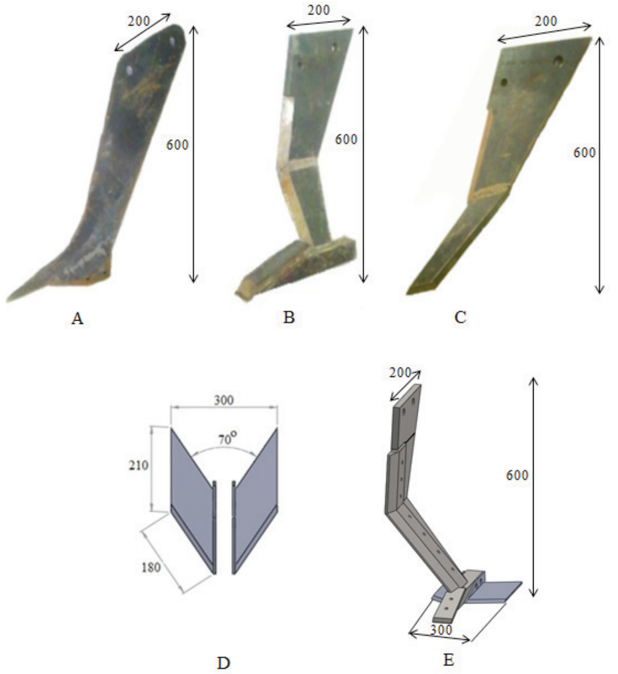

Fig. 1. (A) subsoiler, (B) paraplow, (C) bentleg, (D) top view and accurate dimension of wing and (E) modelled winged paraplow (mm)

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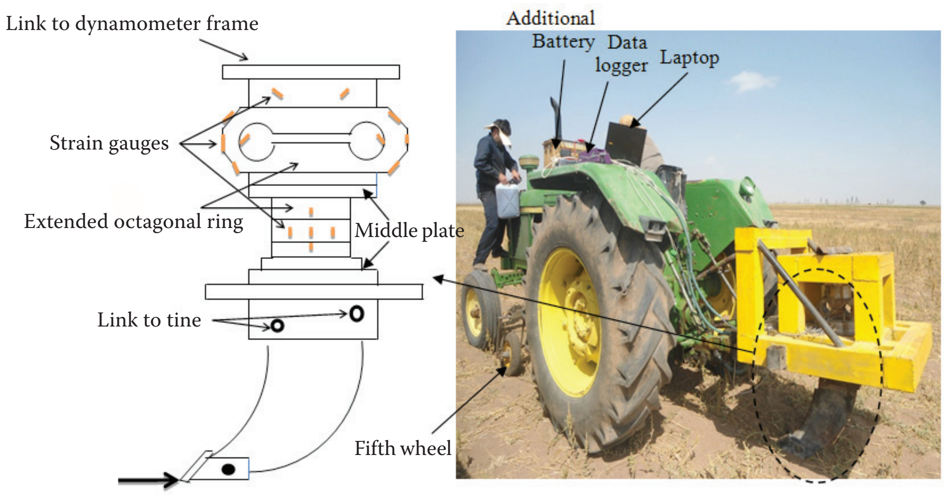

Fig. 2. The dynamometer used in field test

Draft requirement of tines was measured using a dynamometer developed by Abbaspour-Gilandeh and Khanramaki (2013) (Fig. 2). The dynamometer was able to measure the draft requirement up to 35 kN. It consisted of a frame and two extended octagonal rings to measure forces; the tool installed on the dynamometer and the dynamometer attached to the tractor three-point hitch. The other details concerning the design and other aspects of the facility were described by Abbaspour-Gilandeh and Khanramaki (2013).

The dynamometer was calibrated in the field based on the method presented by Askari et al. (2011). The used data acquisition system consisted of commercial strain gauges installed on two extended octagonal rings (EOR), a data logger and a laptop. The signals of strain gauges were digitized in the data logger DT-800 (Data Taker Co., Australia), then were transferred to a laptop. By considering the studied parameters and four replications for each treatment, 240 trials were conducted in a randomized complete block design (RCBD). Each plot was 3 m wide and 30 m long. Soil properties that contribute to tillage energy are moisture content, bulk density, soil texture and soil strength (Sahu, Raheman 2006). The soil of the experimental site was clay loam as presented in Table 2.

A 72.3 kW John Deere tractor (JD-3140) was used for the tests. A RIMIK digital penetrometer (CP20, Australia) was utilized to measure soil penetration resistance. Soil cone index was measured at

Table 2. Analysis of soil at the experiment site

Property	
Sand	40%
Silt	28%
Clay	32%
Organic carbon	0.29%
pH	7.62
EC	0.41 ds/m
Liquid limit	30%
Plastic limit	20.05%
Field capacity(db)	10.13%
Dry bulk density	1,405 kg/m^3
Moisture content (db)	12.4%

EC – electrical conductivity

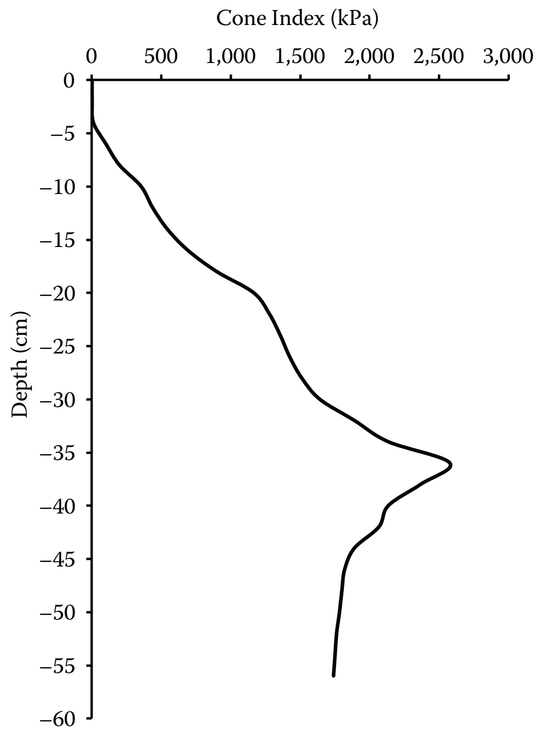

Fig. 3. Results of pre-tillage penetrometry tests of field soil

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30 points in the field over the 0–56 cm depth range and the obtained data were presented in Fig. 3.

Tillage depth was measured by an ultrasonic sensor that was installed under dynamometer frame. This sensor measured the distance between frame and ground surface continuously. Using this sensor, the amount of tillage depth would be measured, accurately. Real forward speed of tractor in the field was measured using a fifth wheel installed in a good location on the tractor left hand (Fig. 2).

Regression prediction model. Prediction models were developed for each tine using the field data of the studied parameters and the SPSS 16 software (SPSS inc., USA). These models were compared with field data to evaluation their accuracy.

RESULTS AND DISCUSSION

The field data were analysed for four levels of forward speed, three levels of depth, three levels of tine and two levels of wing in order to determine the effect of the studied parameters on draft requirements of subsoil tillage tines. Analysis of variance (ANOVA) of the obtained data is presented in Table 3.

Effect of speed on the draft requirement

Fig. 4 shows the effect of speed on draft requirement at three different depths of 30, 40 and 50 cm, respectively, at three tines and two wing conditions. The draft requirement at all of treatments is observed to be increased indicating that an increase of forward speed is an effective parameter to draft. The results of the present study showed there were significant differences of draft at the speeds and different combinations of speed with other variables ($P < 0.01$) with the exception of quadruplet combination of variables that is not significant as presented in Table 3.

Effect of tine on the draft requirement

Table 3 shows there were significant differences of draft at tine and different combinations of tine with other variables ($P < 0.01$) with the exception of quadruplet combination of variables that is not significant. Furthermore, Fig. 4 indicates the effect of tine type on the draft requirement of subsoil tillage tines. It was found that subsoiler, paraplow and bentleg require more draft in all depths and

Table 3. Analysis of variance (ANOVA) of field data with variables of time (*t*), speed (*s*), depth (*d*) and wing (*w*)

Variation source	Degree of freedom	Sum of squares	Mean square	F_s
t	2	3,320.206	1,660.103	4.861**
s	3	69.816	23.272	6.815**
d	2	2,076.256	1,038.128	3.040**
w	1	1,048.239	1,048.239	3.069**
$t \times s$	6	1.252	0.209	61.123**
$t \times d$	4	168.067	42.017	1.230**
$t \times w$	1	181.913	181.913	5.327**
$s \times d$	6	1.27	0.212	61.966**
$s \times w$	3	0.971	0.324	94.752**
$d \times w$	2	8.854	4.427	1.296**
t × s × d	12	0.308	0.026	7.507**
$t \times s \times w$	3	0.068	0.023	6.599**
$t \times d \times w$	2	1.575	0.788	230.64**
$s \times d \times w$	6	0.565	0.094	27.581**
$t \times s \times d \times w$	6	0.014	0.002	0.666^ns
Error	180	0.615	0.003	
Total	239	8,527.473		

**$P < 0.01$; ns – not significant; F_s – factor of significance

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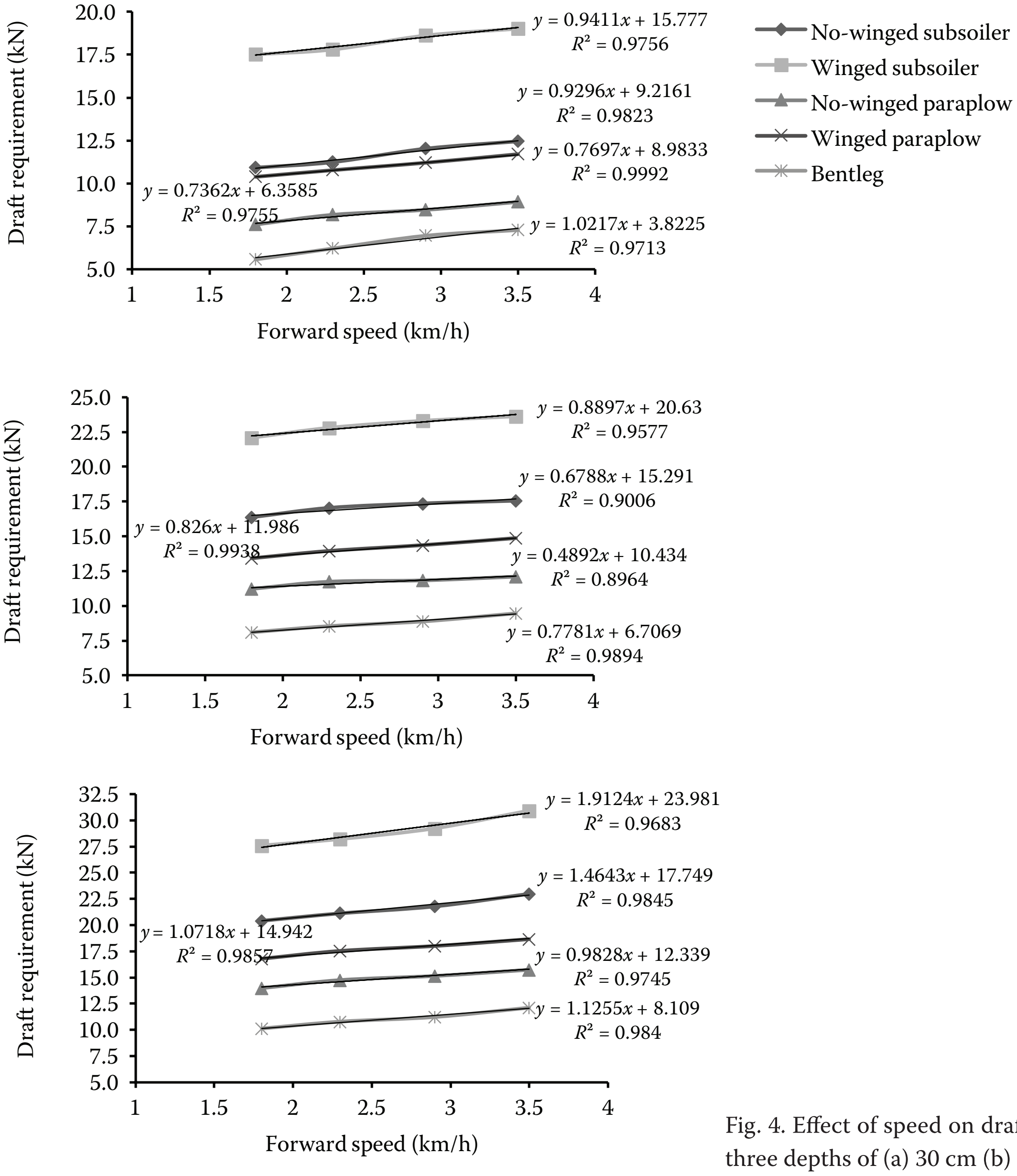

Fig. 4. Effect of speed on draft requirement at three depths of (a) 30 cm (b) 40 and (c) 50 cm

speeds. This relationship was observed by other researchers (Page Harrison 1988; Durairaj, Balasubramanian 1997; Esehaghbeygi et al. 2002, Raper 2005). These researchers reported that the paraplow is energy-efficient because soil failure occurs in tension. Soil has little or no tensile strength; therefore, soil failure in tension would require much less energy than for conventional tillage tools in which the soil is loaded in compression with failure occurring in shear (Page Harrison 1988). Moreover, bentleg requires lower draft than paraplow because the bentleg has no landside and tooth (Thake 1981).

Effect of depth on the draft requirement

The results of the present study showed there were significant differences of draft at the depths and different combinations of depth with other variables ($P < 0.01$) with the exception of the quadruplet combination of variables, which is not significant as presented in Table 3. Fig. 5 shows the changes of draft requirements of different tines, speeds and wings relative to three levels of depths (30, 40 and 50 cm).

It was found that for lower depths, draft increased in all tines, speeds and wing conditions. In all

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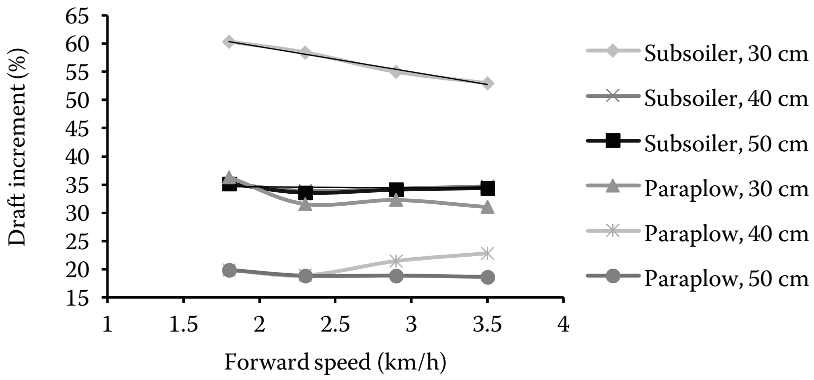

Fig. 5. Effect of adding wing on draft increment at four speeds, two tines and three depths

depths and speeds, winged subsoiler required more draft than others (Page Harrison 1988; Raper 2005). In similar researches, authors reported that increase of subsoiling tillage depth caused the draft increment (Desbiolles et al. 1997; Al-Suhaibani et al. 2006; Ramadhan 2011, 2014).

Effect of adding wing on the draft requirement

Table 3 shows there were significant differences of draft at the wing and different combinations of wing with other variables ($P < 0.01$) with the exception of quadruplet combination of variables that is not significant. Fig. 4 shows that winged tines in all speeds and depths require more draft than no-wing tines. Fig. 5 indicates the draft increment due to adding wing to the subsoiler and paraplow tines. Draft increase by adding wing is due to the increment of soil-tool contact area and consequently increasing metal-soil friction. In addition, the increment of the disturbed area using wing requires more draft force to disrupt and move the soil. Fig. 5 shows that in depths of 40 and 50 cm, draft increment of subsoiler was acceptable (about 35%) but at the depth of 30 cm, draft increment was 55% in mean. A speed increase caused a decrease of draft increment in the depth of 30 cm for subsoiler. This process was not observed for the depths of 40 and 50 cm.

Draft increment in the depths of 40 and 50 cm was similar for both subsoiler and paraplow but draft increment in 30 cm depth was very high. Draft increment by adding wing to the subsoiler was higher than paraplow. The results of this study were similar with researches conducted by Spoor, Godwin (1978) and Ramadhan (2011, 2014) in lower depths of 40 and 50 cm. They reported draft increment of 30%, 30% and 28%, respectively as wings of 30 cm width were added to the subsoiler tine. However, Ahmed, Godwin (1983) reported draft increment of 43%. This and other differences in draft increment can be caused by different tool geometry, working depth and especially soil characteristics. Draft increment by adding wing in paraplow tine was about 20% in the depths of 40 and 50 cm. Similarly; Thake (1981) found that adding wings to the paraplow foot increased the draft requirement of 21%.

Prediction multiple regression models

Three multiple regression models including the studied parameters (speed, depth and wing) were developed to predict the draft requirement for each tine with the exception of bentleg as it would not been winged. The bentleg model includes speed and depth. These models are presented in Table 4.

In these models, d is tillage depth (cm), s is forward speed (km/h) and w is wing width (0 for no-wing tines and 30 cm for winged tines). These equations were evaluated against field draft data in Fig. 6. This figure indicates that the presented models predict the draft requirement of the tested tines accurately (Fig. 6).

Table 4. Prediction models for draft requirement of subsoil tillage tines

Tine	Model
Subsoiler	$-5.942 + 0.507d + 0.906s + 0.221w$
Paraplow	$-3.652 + 0.33d + 0.764s + 0.091w$
Bentleg	$-2.57 + 0.225d + 0.886s$

s – speed; d – depth; w – wing

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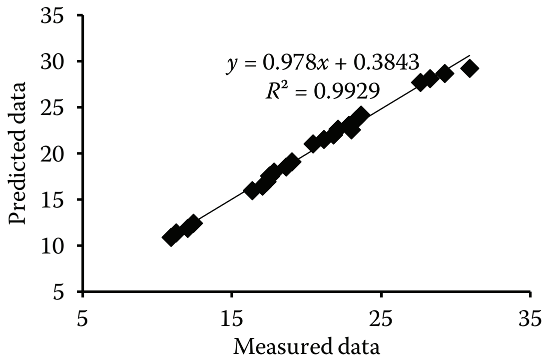

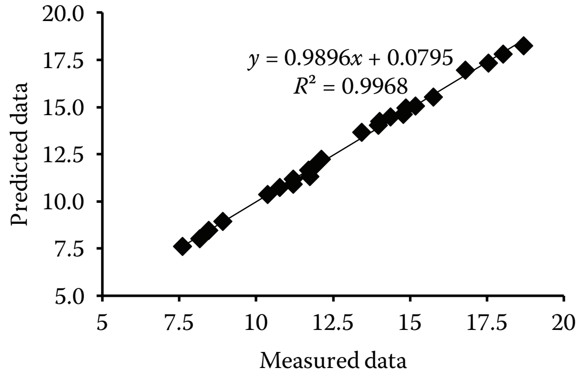

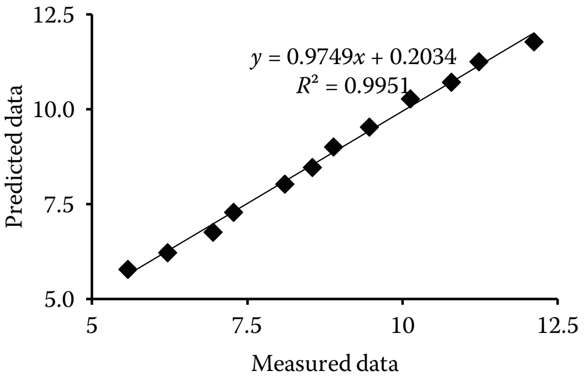

Fig. 6. Predicted values with respect to the measured values (kN) in the tests

CONCLUSION

A research in the field conditions was conducted to investigate the influence of tine, speed, depth and adding wing on the draft requirement of subsoil tillage tines. The conducted runs consisted of three levels of tine (i.e. subsoiler, paraplow and bentleg), four levels of speed (i.e. 1.8, 2.3, 2.9 and 3.5 km/h), three levels of depths (i.e. 30, 40 and 50 cm) and two levels of wing (i.e. no-wing and winged tines). The analysis of variance of the obtained data revealed the following significant consequences. Tine, speed, depth and wing were significant on the draft requirement ($P < 0.01$). Quadruplet interaction effect of these parameters on the draft was not significant. Increment of forward speed, tillage depth and adding wing increased the draft requirement of all tines. The highest values of draft force are related to the winged subsoiler in the depth of 50 cm and speed of 3.5 km/h and the lowest ones are related to the bentleg in the depth of 30 cm and speed of 1.8 km/h. Multiple regression models predict the draft requirement of tines, accurately. It was revealed that draft of the subsoil tillage tines is less affected by forward speed but is much affected by tine type, depth and wing. Additionally, it was found that subsoiler, paraplow and bentleg plough required more draft, respectively.

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